Recent Variability in Surface Water Inundation within Arctic Permafrost Zones: Potential Implications for Regional Methane Emissions

Jennifer D. Watts[1,2], John S. Kimball[1,2], Lucas A. Jones[1,2], Mahta Moghaddam[3]

[1]Flathead Lake Biological Station, The University of Montana 32125 Bio Station Lane, Polson, MT
[2]Numerical Terradynamic Simulation Group, The University of Montana, Missoula, MT
[3]University of Southern California, Los Angeles, CA

Websites: www.ntsg.umt.edu/project/amsrelp & http://freezethaw.ntsg.umt.edu/visualization.htm

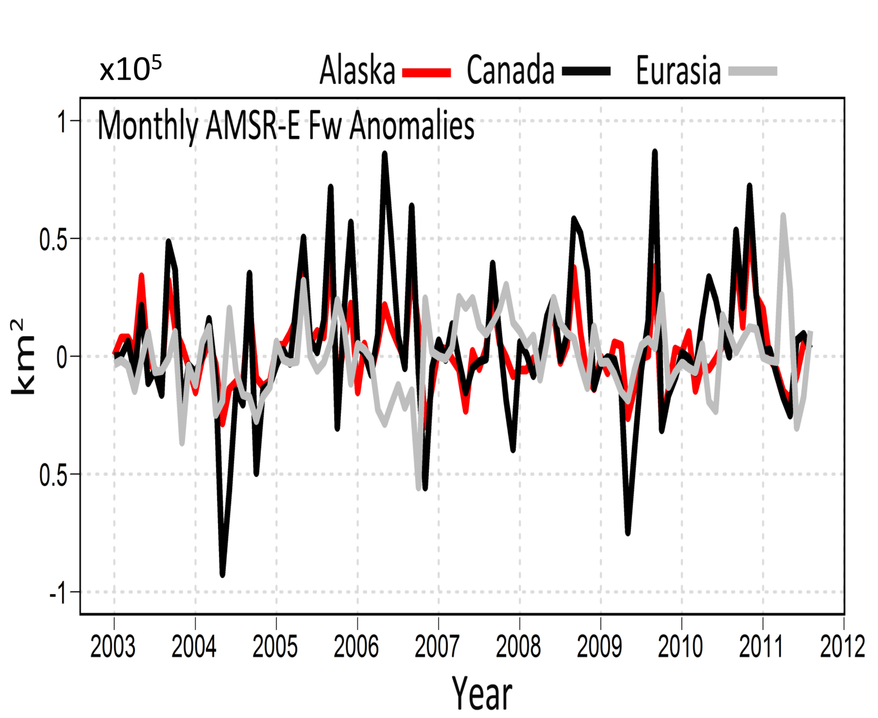
Introduction

Surface water inundation strongly influences methane (CH_4) emissions in the pan-Arctic permafrost regions. Although wet conditions favor methanogenesis, the rate of anaerobic decomposition is strongly regulated by temperature. Periods of wetting and warming can substantially increase regional CH_4 contributions, whereas cooling or drying may reduce the magnitude of emissions. We examine recent (2003-2011) variability in surface water extent across the North American and Eurasian permafrost zones using satellite passive microwave remote sensing retrievals of fractional open water (Fw) derived from Advanced Microwave Scanning Radiometer for EOS (AMSR-E) 18.7 and 23.8 GHz brightness temperatures. The daily Fw retrievals sense sub-grid scale (≤25-km resolution) inundated areas and are insensitive to solar illumination and signal attenuation from clouds, smoke, and other atmosphere effects which constrain optical remote sensing. Potential changes in CH_4 emissions corresponding to Fw and temperature variability are evaluated using a modification of the Joint UK Land Environment Simulator (JULES) wetland CH_4 emission model. In addition to the AMSR-E Fw retrievals, model inputs include mean daily soil temperatures obtained from GMAO MERRA reanalysis and surface metabolic carbon pools derived using a Level 4 carbon (L4_C) algorithm developed for the NASA Soil Moisture Active Passive (SMAP) mission.

JULES CH_4 Emissions Model

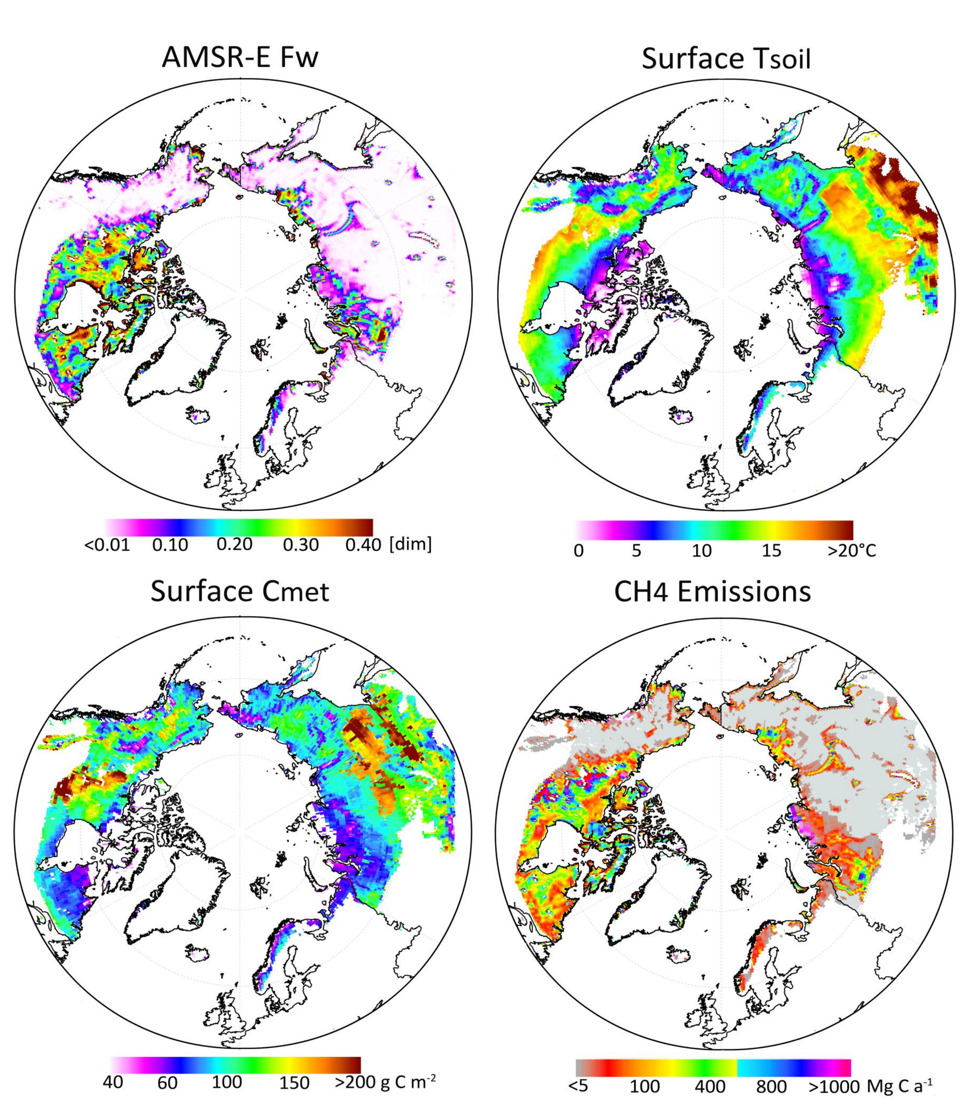
$$F_w(CH_4)=k(CH_4)\cdot Fw\cdot C_{met}\cdot Q_{10}^{(T_{soil}-T_o)/10)}$$

The JULES model estimates CH_4 fluxes according to sub-grid scale Fw area, surface (≤ 10 cm) soil temperature (T_{soil}) and soil organic carbon (Bartsch et al., 2012). The emissions rate constant $k(CH_4)$ is 6.4 x 10^{-5} d^{-1} and the temperature dependence of methanogenesis is represented by a Q10 factor (Q_{10} = 3.4, T_o = 273.15). For this study, input carbon was provided using surface metabolic carbon pools (C_{met}; g C m^{-2} d^{-1}) derived using a Level 4 carbon (L4_C) algorithm (Yi et al., 2013) developed for compatibility with satellite remote sensing retrievals and reanalysis records. Daily T_{soil} (K) records were obtained from the Goddard Earth Observing System Data Assimilation System (GEOS-5) MERRA archive with 0.5 x 0.6° spatial resolution. Sub-grid scale inundated surface area was defined using mean and maximum monthly AMSR-E Fw values (25-km resolution; Jones & Kimball, 2011). Regional variability in AMSR-E Fw and T_{soil}, and corresponding changes in summer (May-August) CH_4 emissions, were evaluated for 2003-2011.



Variability in pan-Arctic Surface Inundation

Surface water inundation in the pan-Arctic permafrost zones is characterized by substantial seasonal and interannual variability. Monthly mean AMSR-E Fw anomalies (**left**) show larger fluctuations in summer inundation occurring in Canada (in black) and Alaska (in red) relative to Eurasia (in grey). Drier surface conditions occurred in 2004 and 2009 throughout the north, reflected in the negative Fw anomalies. Wetter periods in North America include 2005, 2006 and summer 2009 through 2010. For Eurasia, an increase in Fw inundation area is observed in summer 2007 and early spring 2011.

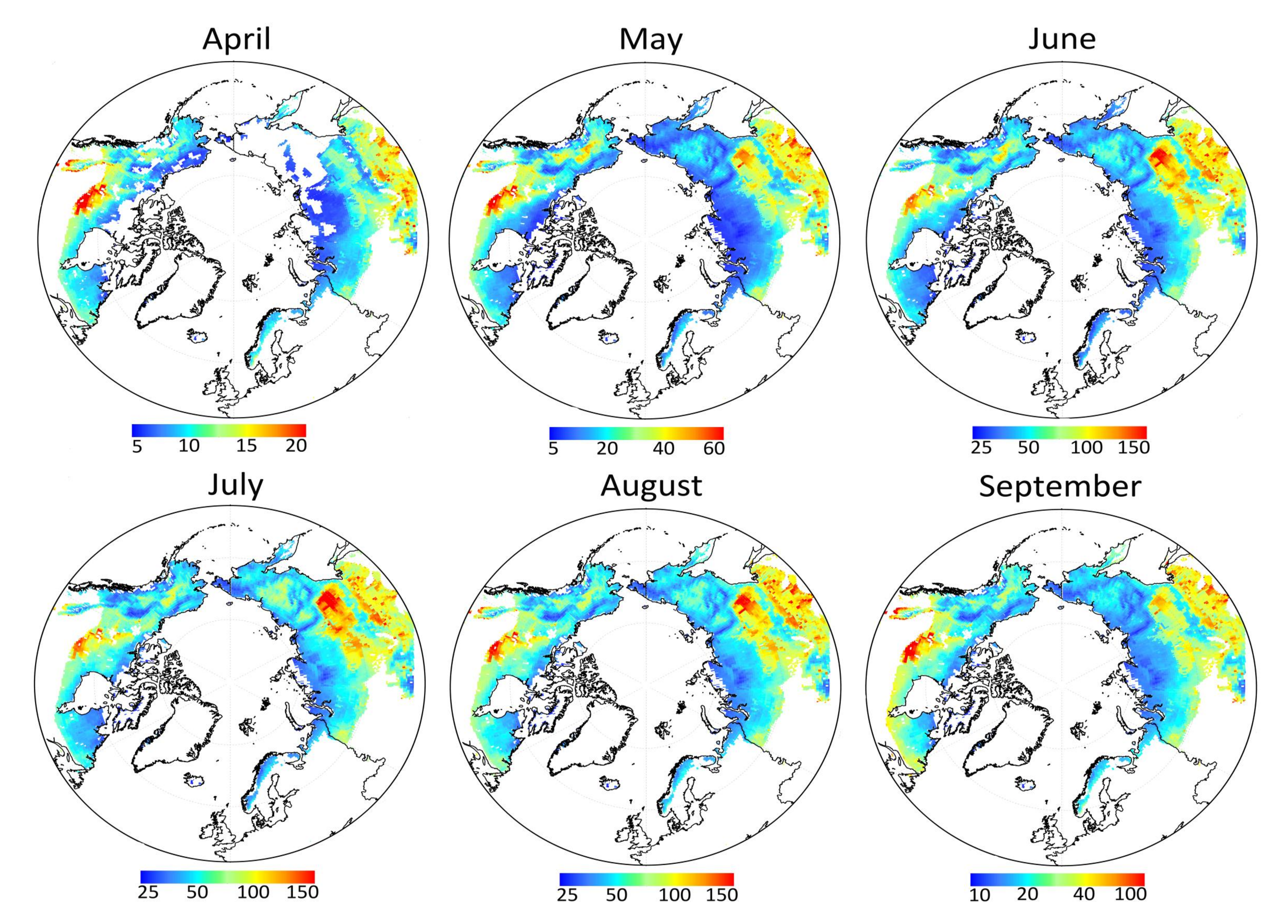


Regional Constraints on Summer CH_4 Emissions

Inputs into the JULES model include inundation area derived from AMSR-E Fw, MERRA T_{soil} and surface C_{met} which provides available carbon substrate for CH_4 production. Although mean summer T_{soil} and C_{met} for the 2003-2011 period are highest in southern Siberia and the western Canadian Shield region (**left**), a majority of permafrost zone CH_4 emissions occur within wetland complexes in Canada, coastal Alaska, and the Ob-Yenisey and Volga river lowlands. Fw inundation extent is widespread in these regions throughout the non-frozen season. Elsewhere, CH_4 contributions are more prevalent following late spring snow and ice melt, and are greatly reduced by regional summer drying.

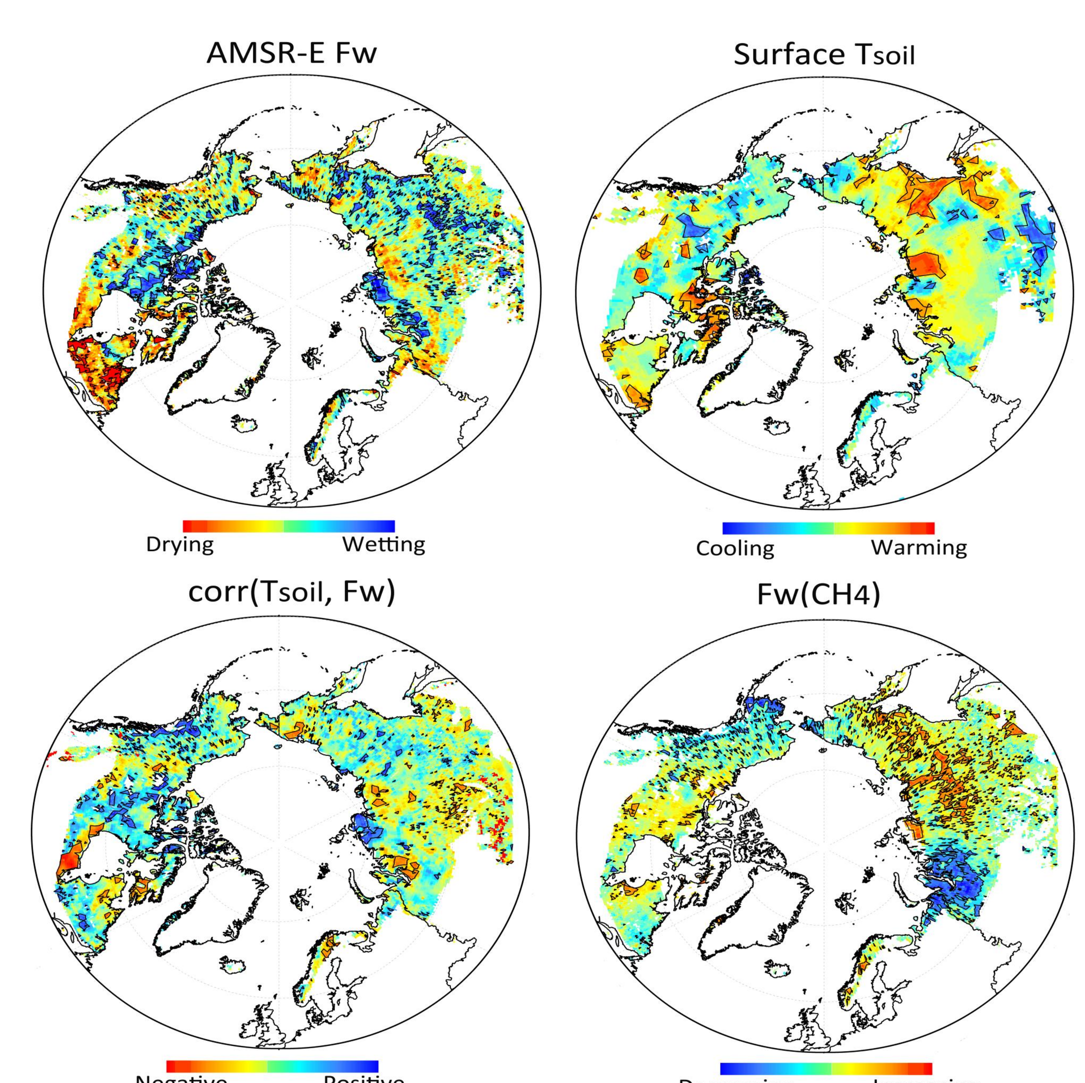
Model Simulation Results

Estimated Monthly CH_4 Fluxes



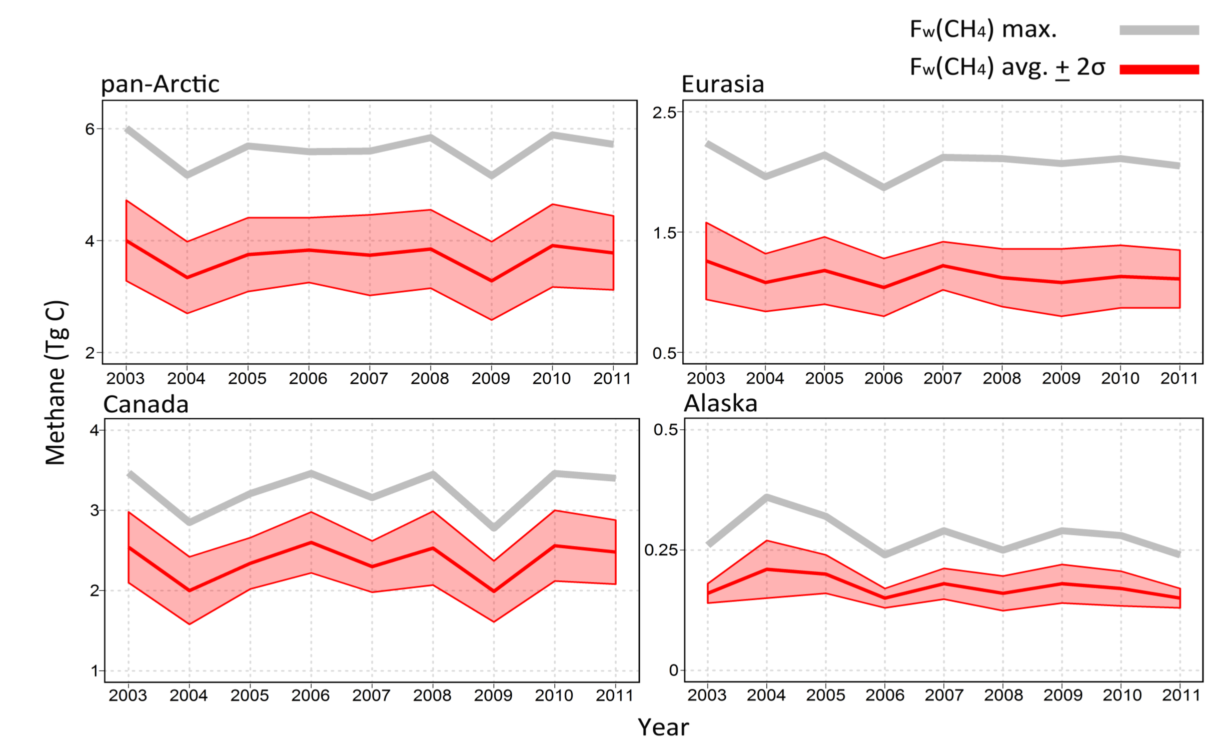
Mean summer (2003-2011) CH_4 fluxes from the JULES model simulations (**above**) reflect strong surface temperature controls on gas emissions within permafrost landscapes. In April, frozen surface water minimizes Fw and CH_4 fluxes. The northward progression of warming is observed in May and June, with peak CH_4 emissions in July and August. Summer fluxes are highest (>150 mg C m^{-2} d^{-1}) within the CN Mackenzie River basin and southeast Siberia, which reflect a combination of warmer temperatures and higher C_{met}. Without constraining regional fluxes by Fw area, the total summer (May through August) CH_4 emissions averaged 97 Tg C. This decreases to 4 and 6 Tg C, respectively, when the daily CH_4 fluxes are constrained to inundated surfaces represented by the mean and maximum monthly Fw records.

Regional Changes in Surface Controls and Summer CH_4

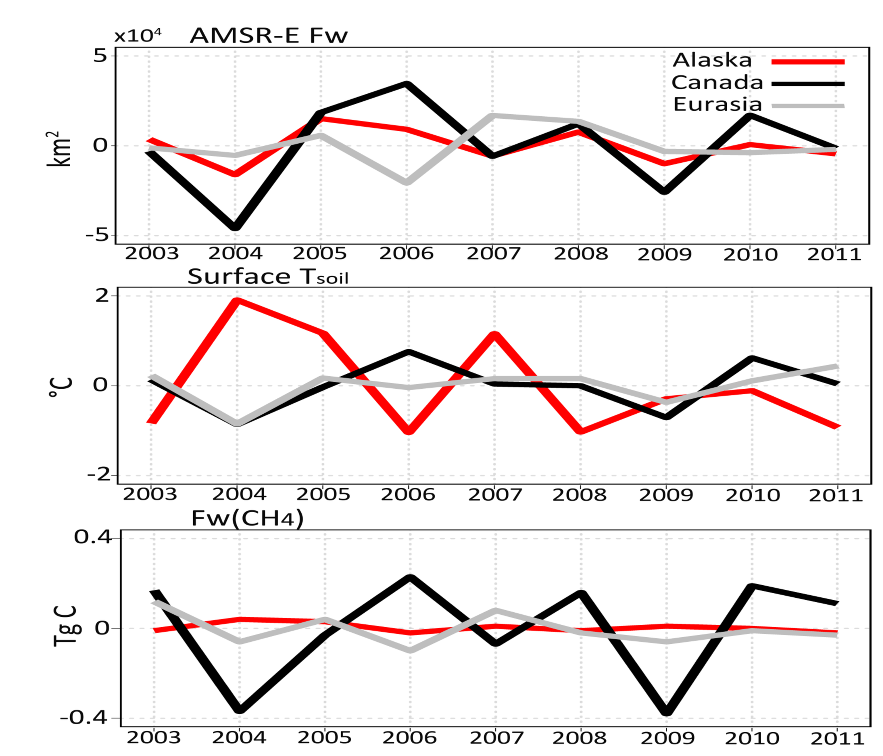


Estimated summer Fw, T_{soil}, and CH_4 emissions from 2003-2011 shows widespread wetting throughout the pan-Arctic continuous permafrost zones (Watts et al. 2012) and regional surface warming (**above**). Areas having significant ($p<0.1$) change are outlined in black. Positive correspondence between AMSR-E Fw and MERRA T_{soil} occurs throughout the northern domain. However, in some areas (e.g. Hudson Bay Lowlands) surface warming coincides with lower summer inundation, which may reflect shifts in precipitation or drainage subsidence associated with thawing permafrost. These results show increasing summer CH_4 emissions in eastern Siberia coincident with recent warming and wetting. In contrast, decreases in regional CH_4 contributions in the Ob-Yenisey and Volga wetlands complex and throughout Alaska are influenced by recent summer T_{soil} cooling.

Impacts of Climate Variability on Permafrost CH_4 Emissions



Model simulations show relative stability in CH_4 emissions for pan-Arctic permafrost regions, but also reflect interannual variability in Fw inundation and temperatures (**above**). Relative to Eurasia, larger CH_4 fluctuations in Canada reflect greater Fw inundation extent and corresponding sensitivity to summer temperature changes. The weak (p=0.27) decrease in Alaska CH_4 emissions reflects regional cooling. Summer Fw and T_{soil} anomalies (**below**) illustrate regional differences in climatic variability and the potentially contrasting influence on CH_4 emissions; this is particularly evident in 2004 where summer warming in Alaska offsets lower Fw inundation, resulting in increased CH_4 fluxes.



Study Summary

- The 2003-2011 AMSR-E Fw record indicates large interannual variability in pan-Arctic summer surface inundation, and widespread wetting throughout the continuous permafrost zone. Although localized wetting corresponds to changes in surface temperature, as was observed in this study, it may also be influenced by shifts in precipitation and permafrost degradation.
- Although the major wetlands complexes in Canada and Russia were the primary contributors to CH_4 efflux, increases in summer CH_4 fluxes throughout northern Siberia coincide with regional wetting. In comparison, declines in CH_4 emissions in Alaska and western Eurasia correspond to regional surface cooling.
- This study highlights the dynamic surface temperature and Fw inundation changes within pan-Arctic permafrost regions. The potentially contrasting influence of temperature and surface moisture on regional CH_4 emissions underscores the importance of monitoring these two factors to better characterize and constrain regional CH_4 emissions within the northern high latitudes.

References & Acknowledgement

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